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Smart Heat-health Action Plans: A Programmatic, Progressive and Dynamic Framework to Address Urban Overheating

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KEYWORDS

- extreme heat
- urban overheating
- smart heat-health action plan
- long-term planning
- collaborative approach
- urban sustainability

ABSTRACT

Cities stand at the focal point of vulnerability to heat waves (HWs) as they threaten urban livability and sustainability. National, regional, and local heat-health action plans (HHAPs) are vital for combating HWs and are increasingly crucial as adaptation measures to extreme heat. The present article highlights the most recent development on the working mechanism of HHAPs, its contemporary challenges, barriers to it and a range of operational heat management and planning strategies. It introduces the concept of 'smartness' to the existing mechanism of HHAPs which holds a significant potential to be intelligent, explicit and dynamic to address the growing and multifaceted impacts of extreme heat. It emphasizes urgent priorities including long-term heat planning, multisectoral heat-early warning systems, building urban heat resilience and recommends the application of eight core elements endorsed by the World Health Organization (WHO) for effective implementation of HHAPs. Collaboration among meteorological, epidemiological, public health, and urban planning experts is essential for addressing the multidimensional challenges of extreme heat.

Introduction

The phenomenon of global warming has substantially escalated climate-related challenges and occurrence of extreme weather events. Global climate change causes a serious increase of the frequency, magnitude and duration of extreme heat events (EHEs) or HWs (Perkins, 2015). HWs are characterized as extended durations of abnormally elevated temperatures and has emerged as the deadliest climate risk contributing to thousands of preventable deaths each year (IPCC, 2018, 2022). Extreme heat is a complex hazard that presents risks both acute and chronic. Recently, climate scientists and experts have dedicated their attention to a greater disconcerting occurrence commonly referred to as 'global boiling' indicating a heightened intensification of temperature extremes (Amnuaylojaroen, 2023; Thomas, 2023). In the context of the shift from global warming to global boiling, an expanding corpus of research efforts have underscored scientific investigations of EHEs in urban areas (Santamouris, 2020; Nazarian et al., 2022, 2024; Feng et al., 2023; Ghosh & Vidyasagar, 2023).

Urban heat island (UHI) is a widely environmental phenomenon where urban areas experience significantly higher temperatures compared to their rural surroundings (Wouters et al., 2017; Kotharkar et al., 2024c). Urban overheating is the combined effect of frequent HWs and growing heat islands associated with anthropogenic climate change and rapid urbanization (Santamouris, 2020;

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Kotharkar et al., 2024a). Their significant ramifications on environmental, economic, social, and health aspects have also been widely reported (Ebi et al., 2021; Kotharkar et al., 2019, 2021, 2022). In recent years, the frequency, duration, intensity, and seasonality of EHEs have escalated quickly, and are projected to increase in the future (IPCC, 2022). The multifarious impact of HWs is threatening the livelihoods and sustenance of urban dwellers and profoundly affects the livability and sustainability of cities (Kotharkar et al., 2024b). Such a scenario presents an immense threat to swiftly urbanizing areas and burgeoning populations.

In this context, HHAPs and heat action plans (HAPs) were introduced as a guide to minimize the adverse effects of extreme heat and enhancing public health responses to extreme heat through a series of coordinated efforts between specialized agencies (WMO and WHO, 2015; Casanueva et al., 2019; He, 2023; Ulpiani et al., 2024). HHAPs provide a strong framework dedicated to address heat vulnerability and serve as an effective tool for directing heat-related adaptation and mitigation strategies across different spatial scales. In scientific literature, the terms 'HAP' and 'HHAP' have been interchangeably used. While both plans aim to mitigate the effects of extreme heat, HAPs have a broader focus on overall heat management, and HHAPs specifically address health-related concerns and strategies (Guardaro et al., 2020; He, 2024). A HAP is primarily concerned with general strategies for managing and responding to extreme heat which includes measures related to infrastructure, emergency response, public awareness, and logistics. HAPs have a broader scope that includes general preparedness to address a wider range of stakeholders and is particularly evident in Asian and Western Pacific countries. In contrast, HHAPs specifically target the health impacts of extreme heat and is focused on protecting public health and minimizing heat-related morbidity and mortality (Martinez et al., 2019; Li et al., 2022). HHAPs, a characteristic of European and Eastern Mediterranean nations often targets health professionals and protect vulnerable populations (Martinez et al., 2022).

In this regard, the sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) alerts of a faster warming trend across most of the land areas (IPCC, 2022). It confirms that without constructive adaptation solutions, heat extremes will be unbearable for human health. The present study undertakes the following key pointers:

1. The escalation of extreme heat poses growing health hazard, propelled by the rapid urbanization and demographic shifts in nations with aging populations.
2. Globally, the exposure of populations to HWs is poised to amplify alongside further warming, exhibiting pronounced geographical variations in heat-related fatalities unless additional adaptation measures are undertaken.
3. Projections suggest that potent geographical differentials in heat-induced mortality will emerge in the latter part of this century, predominantly steered by population expansion in regions characterized by tropical and sub-tropical climates.
4. Within cities, hot extremes including HWs have intensified, amplifying heat risks, particularly within urban areas, attributable to alterations in regional heat patterns compounded by the 'heat island' phenomenon.
5. Adaptation strategies necessitate action plans integrating early warning systems and responsive protocols to mitigate heat-related risks.
6. Future heat risk adaptation options entail comprehensive arrangements featuring early warning systems and response strategies tailored for both urban and non-urban locales, with a focus on safeguarding vulnerable demographics through iterative enhancements.
7. Addressing short-term heat-health hazards can be complemented by long-term urban development strategies, incorporating nature-based solutions to mitigate UHI effects.
8. Embracing a multi-sectoral approach, involving diverse stakeholders, holds promise in fortifying responses to enduring heat risks, with initiatives encompassing climate-conscious urban planning and design measures.

Aim, objectives and scope

Underscoring these facts, this paper aims to detail the significance and critical functioning of HHAPs apropos of rapid urban growth and rising EHEs and envision a smart version to tackle the multi-dimensional nature of extreme heat. The research is primarily divided for a three-fold purpose with a intent to serve unique objectives, which are to (i) outline contemporary extreme heat-related efforts within the HHAPs including the wide range of extreme heat countermeasures as prescribed by international bodies or organizations; (ii) identify the limitations, barriers, and challenges in operationalizing heat management and heat planning strategies/efforts; and (iii) propose the development of a smart HHAP which is an evidence-based programmatic and progressive pathway to counter the evolving and multi-faceted impacts of extreme heat. The present study does not account for the cultural, political, economic and complex physiological factors related to the operational mechanism of HHAPs.

Methodology

The present research critically examined the current progress in extreme heat management and planning with a focus on identifying the key concerns in the operational mechanism of HHAPs. It adopts a mixed-method approach and go beyond a review of existing literature. It recognizes limitations and barriers in the effective functioning of a HHAP via a critical review and suggests key recommendations to augment the overall efficacy and operation of action plans. In addition to policy documents, the representative sample of peer-reviewed original research was limited to those focused on mitigation or adaptation solutions as a part of broader action plans (HAPs, HHAPs, and heat response plans). The review was restricted to publications available online, excluding those published in physical journals or books and any studies with restricted access. The paper concludes with key recommendations for both researchers and policymakers including the need for a smart HHAP to offer a dynamic stance involving active collaboration among various specialized sectors.

Literature review

This section summarizes the global efforts to counter the threat of HWs including the discussion of international polices and guidelines and their recent developments. Thirdly, it details the core concept or the basic working mechanism of HHAPs which includes a range of contextual and cross-cutting extreme heat countermeasures. Lastly, it discusses the issues, barriers, and challenges in the contemporary extreme heat management and planning efforts which paves the way for the ideation of smart HHAPs.

International efforts and guidelines to address extreme heat

International scientific bodies including the IPCC, WHO, and WMO, concur that the impacts of extreme heat can be mitigated through concerted efforts, necessitating a comprehensive array of actions with active coordination among diverse agencies (IPCC, 2022; WHO, 2008; WMO &WHO, 2015). In response to the rising incidence of EHEs, national governments and international organizations instituted heat-health warning systems (HHWSs) during the 1990s (Ebi, 2007, 2019; Sheridan & Kalkstein, 2004). The inception of the first hot weather health watch/warning system in Philadelphia, USA, in 1995 marked a pivotal moment (Kalkstein et al., 1996), followed by the large-scale public health interventions initiated in the aftermath of the 2003 European HW (Wilhelmi & Hayden, 2010; Keith et al., 2022). These initiatives catalyzed the development of numerous national and sub-national heat-health frameworks worldwide. Subsequently, various countries embarked on heat-health research to formulate implementable action plans. Many communities and states have since established HHAPs to effectively manage the public health consequences of HWs, incorporating early warning and effective response systems (Casanueva et al., 2019; Martinez et al., 2022). In 2008, the WHO Regional Office for Europe played a crucial role in guiding the development of HHAPs, providing comprehensive guidance documents and supplementary materials for the preparation of these plans (WHO, 2015; WMO & WHO, 2015). These resources have been widely adopted by national, regional, and local authorities as a blueprint for the prevention and management of HWs (WHO, 2011; WMO & WHO, 2021; Martinez et al., 2019, 2022; WHO, 2021).

The establishment of the Ahmedabad HAP in 2013 marked a significant milestone, pioneering the approach in the South Asia region (Kotharkar & Ghosh, 2021b). Since then, many countries have adopted similar action plans, wherein the onset of hot weather triggers a range of interventions aimed at minimizing health impacts. However, national HHAPs are currently operational in only 47 countries, with the majority situated in Europe (35), followed by South-East Asia (5), Western Pacific (4), Americas (2), and Eastern Mediterranean (1) (Kotharkar & Ghosh, 2021a). In 2021, the WHO Regional Office for Europe conducted a survey on the status of national/federal heat-health prevention across its member states, revealing significant variations in the implementation of core elements of HAPs (WHO, 2021). Nevertheless, there is strong evidence of progressive improvement in the development and implementation of HHAPs within the WHO European and South-East Asian region (Martinez et al., 2019, 2022; WHO, 2021).

Recent developments on extreme heat-related countermeasures

Extreme heat prevention efforts became more systematic and institutionalized since the aftermath of the 2003 European HW which led to over 70,000 excess deaths (He et al., 2023). HHAPs have surfaced prominently in regions grappling with rapidly escalating urban heat challenges, showcasing promising momentum, particularly in South-East Asia, the Eastern Mediterranean, and the Pacific. Additionally, stakeholders from diverse disciplines and organizations, including the Natural Resources Defense Council (NRDC), Red Cross, and regional partners, are actively collaborating with national governments to deepen understanding of the causes and formulate effective responses to this pressing risk. Concurrently with preventive measures, there has been a surge in research and publications focusing on HHAPs, both on a global scale and within Europe (Campbell et al., 2018; Casanueva et al., 2019; Santamouris, 2020; Nazarian et al., 2022, 2024; Ulpiani et al., 2024).

Over the past decade, numerous member states within the WHO European Region have instituted HHAPs of diverse scopes and complexities. Major states/cities in India vulnerable to HWs have their own plans, though active participation of local governments is limited (NDMA, 2019). Several states in the US including Kansas, Minnesota, and Wisconsin have developed specific guidelines to increase awareness and readiness among the population while a few others have employed heat officers to ensure priority action for local governments (Keith et al., 2021). Select cities including Arizona and Sydney have collaboratively developed extreme heat planning toolkits with support from local governments. These toolkits harness the latest research, information, and innovative ideas to facilitate the adaptation of urban spaces and enhance resilience against extreme heat (WSROC, 2021; Keith & Meerow, 2022). Additionally, collaborative efforts by the international organizations are underway to enhance guidance on heatwave and heat health early warning systems, through the Global Heat Health Information Network (GHHIN).

Understanding the working mechanism of HHAPs

The beginning of the twenty-first century has witnessed the initiation and development of cross-cutting extreme heat countermeasures. HHAP epitomizes practical and policy action/response to the negative effects of extreme heat to be undertaken at different levels and scales. HHAPs offer a comprehensive guide to minimize the negative impacts of extreme heat and delineate a portfolio of actions for the prevention and management of HWs. It offers a definitive mechanism to influence built environment outcomes, improve public health responses and controls that have the potential to reduce the impacts of urban heat. This includes a wide range of guidelines ranging from the formation of a lead body, meteorological early warning systems, timely public and medical advice, improvements to housing and urban planning and ensuring preparedness of health care and social systems (WHO, 2008; WMO & WHO, 2015, WHO, 2021). Additionally, it outlines a variety of spatio-temporal actions for concerned stakeholders and advocates periodic monitoring and evaluation of processes and outcomes to ensure the effectiveness of intended activities.

HHAPs encompass a comprehensive set of guidelines designed to facilitate various facets of heat risk reduction and preparedness. They serve as a vital tool for identifying and implementing heat-related adaptation and mitigation strategies. In recent years, HHAPs have emerged as indispensable instruments for guiding measures against extreme heat, continually evolving to enhance their effectiveness. Established HHAPs have demonstrated success in mitigating heat-related mortality and its adverse impacts. The WHO's guidance on HHAPs acknowledges that the detrimental effects of HWs are largely preventable, necessitating specific actions at multiple levels for successful implementation (WHO, 2008). These actions are integrated within HHAPs, which comprise robust health preparedness systems, epidemiological evidence, precise meteorological early warning systems, and enhancements in urban management and planning. Further, it acknowledged the need for heat-health systems to strengthen stewardship functions and a proactive, multidisciplinary, and multi-sectoral approach with governments, agencies, and international organizations.

Contemporary issues, barriers, and challenges in extreme heat management efforts

Despite making commendable national and regional initiatives along with international efforts, there remains significant gaps in the HHAP apparatus and its operation. The current mechanism of HHAP remains static in function, rigid in replication, and unprogressive in nature. Most of the heat plans focus on managing the negative consequences of extreme heat rather than long-term climate change adaptation and heat-health planning. It is also evident that response measures to HWs are primarily short-term, reactive in behaviour, and fail to capture and treat pseudo-effects at large. Current heat plans do not account for changing climates and hence do not provide a dynamic solution to the multifarious impacts of HWs. Furthermore, the effectiveness of HHAPs is significantly hampered by the absence of periodic monitoring and evaluation mechanisms. There is a notable deficiency in frameworks designed to assess the efficacy of policies in diminishing heat-related mortality and morbidity. The present study highlights a few shortcomings in contemporary extreme heat management efforts:

1. Lack of consistency in defining HWs and its poor scientific understanding
2. Threshold definition and its limited application in HHWSs
3. Static heat alert systems and action plans
4. Restricted coverage of HHAPs
5. Limited knowledge of intra-urban heat vulnerability and heat hotspots

It is clearly manifested that the widespread impact of HW leads to public health deterioration and increased risk of heat-related morbidity and mortality. In addition to this, the present research identified several ripple effects of extreme heat on urban systems which adds further burden on intended measures:

1. Higher energy consumption coupled with dangerous levels of pollution
2. Damage to urban infrastructure and services
3. Loss of economy and workers' productivity
4. Exacerbated water stress and widespread droughts
5. Power outages and energy crisis

In addition to the above-listed issues, HHAPs also face implementation failures, data-sharing and are not adequately resourced. Most heat plans specify roles and responsibilities at the national level but lack specificity at the sub-national and local levels. In terms of linkages with other policies, HHAPs are less frequently integrated and barely a part of environmental/disaster management policies. The key challenges for HHAPs that hinder their overall functioning are:

1. Lack of trained/skilled manpower to implement heat-related countermeasures
2. Inadequate weather stations to record meteorological data
3. Poor integration of HHAPs with national planning policies & development plans
4. Limited real-time surveillance
5. Inadequate monitoring and evaluation of processes/outcomes

Smart HHAP: A programmatic, progressive and dynamic framework

In view of the growing heat stress in urban areas, it is important to expand extreme heat adaptation and improve heat-related preparedness through a holistic and anticipatory approach. The multifaceted and growing impacts of extreme heat call for an urgent and collaborative mechanism coupled with long-term investment in research and innovation. The global community and policymakers need to look beyond short-term solutions to promote long-term urban heat resilience. The next section outlines a range of constructive recommendations best suited to application in their unique contexts in synchronization with the suggestions given by the IPCC AR6 report.

In this context, we introduce the concept of 'smartness' to the existing working mechanism of HHAPs. A smart HHAP by design refers to a programmatic, progressive and dynamic framework to mitigate urban overheating involving the collaborative intervention of multiple specialized sectors (see Fig. 1). This enables its operation to be intelligent, explicit, and dynamic to address the multifaceted aspects of extreme heat primed for effective reduction of negative heat-health outcomes. It involves a combination of countermeasures to protect public health, infrastructure, and the environment. The present work proposes a

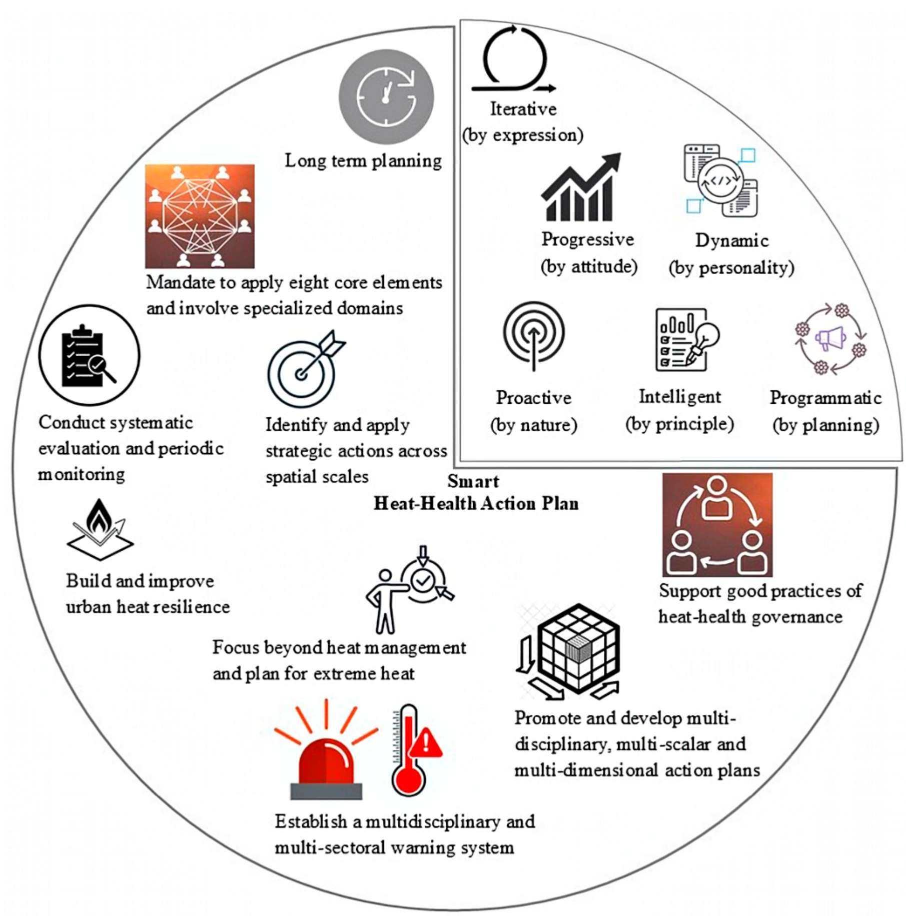

Figure 1. Working framework of a functioning smart HHAP

few directives as a part of smart HHAPs against the setting of changing urban landscape, fluctuating climate, and worrying future weather projections of temperature extremes. It sets an agenda to augment the overall efficacy and operation of HHAPs via condensed multidisciplinary directives which includes:

a) Long-term planning

Extreme heat is a silent killer and poses a huge challenge to sustainable development. The majority of contemporary extreme heat countermeasures and their respective application remain reactive and short-sighted. Urgent attention should be directed towards substantial and targeted adaptive investments, particularly aimed at safeguarding the most vulnerable populations (WHO, 2008; WMO & WHO, 2015; Ebi, 2019; Ebi et al., 2021; WHO, 2021). Comprehensive efforts must encompass year-round planning and the development of threshold-based heat metrics to bolster early warning systems (Li et al., 2022; Brimicombe et al., 2024). Smart HHAP offers a holistic approach encompassing diverse actions such as land-use planning, climate-responsive building design, community resilience, and emergency planning and response to effectively manage long-term heat risks. Furthermore, advancements should entail documenting the contributions and interactions of controllable and non-controllable factors influencing the UHI effect, identifying and addressing sources of heat vulnerability among the population, and enhancing heat risk management through comprehensive emergency response preparation and inter-agency collaboration (WHO, 2021; Keith et al., 2022). These multifaceted approaches hold promise in mitigating the impacts of EHEs, thus fostering greater resilience within communities.

b) Mandate: apply eight core elements and involve specialized domains

Extreme heat countermeasures often remain ineffective and fail to cover a wider audience due to their siloed operation. This creates and calls for the need for an inclusive approach consisting of diverse stakeholders with a set of expertise to join hands and effectively contribute towards a holistic reduction of heat-related impacts. This particularly applies to the formulation of HHWS, which is part of wider HHAP and can be improved by knowledge sharing and active collaboration between stakeholders (WMO & WHO, 2015; WHO, 2021; Brimicombe et al., 2024). Therefore, it is urgent to prioritize the development of a robust plan that integrates meteorological warnings and public health interventions, supported by epidemiological data, coupled with appropriate urban planning strategies. Local conditions will dictate the plan's details, but practice in different parts of the world has demonstrated that core elements are indispensable (Casanueva et al., 2019; WHO, 2021). These have been highlighted by a guidance document for the preparation of HHAPs as published by WHO including (WHO, 2008):

1. Establishing agreement on a lead body tasked with coordinating and facilitating collaboration among relevant stakeholders.
2. Ensuring clear links and effective communication channels between national and community early warning systems, extending to all pertinent stakeholders for achieving last-mile connectivity.
3. Identifying vulnerable groups and areas requiring priority response guided by a comprehensive heat-health information plan.
4. Implementing evidence-based triggers and graduated thresholds for action, tailored to locally appropriate metrics such as temperature, humidity, and the anticipated duration of the heat event.
5. Enacting appropriate early and anticipatory actions to mitigate risks and safeguard both people and livelihoods.
6. Establishing operational preparedness and readiness measures for local first responders for swift and effective response.
7. Developing a robust public communications plan, incorporating nationally harmonized, action-oriented key messages, for disseminating critical information to the public.
8. Implementing real-time monitoring, evaluation, and learning mechanisms for continuously assessing the effectiveness of interventions and fostering iterative improvements.

c) Identify and apply strategic actions across spatial scales

Smart HHAP advocates the application of temporal actions i.e., short-term, medium-term and long-term measures to manage, respond, and plan for extreme heat risks respectively (refer Fig. 2). While short-term actions are aimed at immediate or relatively temporary solutions (0-6 months) and are usually applied after a HW has struck or during a hot weather season, medium-term actions (6-24 months) cover extended efforts to manage/control the adverse effects of HWs. Long-term efforts are largely executed through substantial time and planning involving future considerations for several years. Smart HHAP embraces a nested governance approach which entails working concurrently across various scales, ranging from the design of microclimates at specific sites to broader neighborhood, city, and regional planning scales, and can lead to sustainable extreme heat considerations (Keith et al., 2019; 2022; WHO, 2021). Growing emphasis on regional heat planning recognizes the territorial impact of HWs and the climatic effects of different land use or policy changes (Nazarian et al., 2022; Ulpiani et al., 2024). A robust action plan

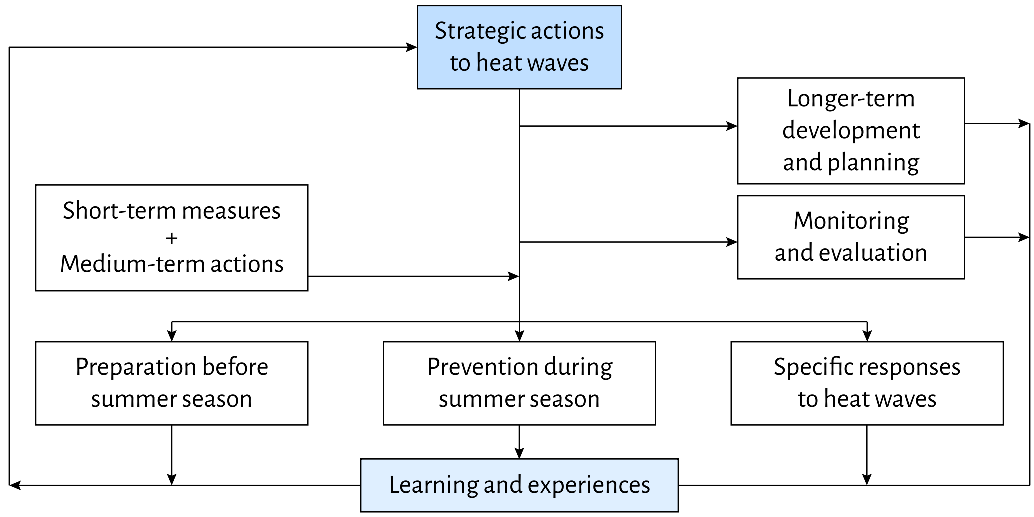

Figure 2. A periodic extreme heat planning and management cycle

should entail these strategies and planning interventions to prevent as well as to prepare. Subsequently, implementation of the plan and its elements depends the periodic monitoring and evaluation of intended measures drawing from past experiences. This forms a circularity in action planning template which can break large plans into smaller implementable actions while providing clarity towards the course of action.

d) Conduct systematic evaluation and periodic monitoring

Evaluation of HHAPs encompasses two primary categories: '*process*' evaluations, which assess whether their implementation aligns with its intended objectives, and '*outcome*' evaluations, which gauge their effectiveness in mitigating the adverse impacts of extreme heat (WHO, 2021; Dwyer et al., 2022). However, the evaluation of processes remains largely underrated and undervalued, impeding the formal assessment of HHAP components, roles, and the potential efficacy of implemented measures. Thorough assessment and evaluation of actions taken before, during, and after HW events are crucial for enhancing the effectiveness and continual improvement of HHAPs. Subsequently they can serve as crucial adaptation solutions, thus underscoring the importance of their evaluation and iterative updating in response to evolving climate dynamics and changes in heat-health associations. The development of progressive methodologies and inclusion of socio-economic factors are critical aspects and can facilitate effective and comprehensive responses. Evaluation involves a multidisciplinary and collaborative effort among various stakeholders to address the diverse aspects and components of the HHAP, including user needs and potential challenges (refer Fig. 3). Formal evaluation of HHAP effectiveness is important to:

- assess whether activities are achieving their intended outcomes;
- evaluate the cost-effectiveness of activities;
- assess whether the implemented measures are ethical and address health inequalities
- determine if activities are acceptable to the target population;
- ensure that evaluation is integrated at every stage of the planning, development, implementation, and review of programs
- track health impacts and changes over time

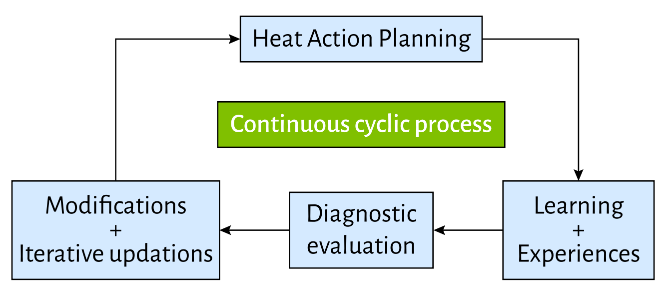

Figure 3. Evaluation and monitoring of HHAPs

e) Establish a multidisciplinary and multi-sectoral warning system

As a wider component of HHAP, HHWSs use forecasts of high-risk weather conditions to trigger public health warnings (Sheridan & Kalkstein, 2004; VanderMolen et al., 2022). Ideally, warning systems should encompass a comprehensive, multi-stakeholder action plan that can be established at various levels, including national, regional, or local. The efficacy of HHWSs should rely on threshold-based assessments rather than absolute weather parameters (Li et al., 2022; Brimicombe et al., 2024). It is imperative to develop thresholds that integrate thermo-physiological considerations and account for seasonal variations (Casanueva et al., 2019; Martinez et al., 2022). Such efforts should be founded on robust scientific principles, drawing upon extensive and long-term data, complemented by relevant health statistics. This approach can significantly enhance the applicability of thresholds and indicators in decision-making contexts. Substantial investments can be directed towards impact-based forecasts, which integrate meteorological data with vulnerability information to offer timely analyses and provide lead time in diverse settings.

f) Promote and develop multi-disciplinary, multi-scalar and multi-dimensional action plans

The existing HW management and planning systems lack the ability to replicate adaptation efforts across different spatial scales. Current efforts primarily focus on physical/engineering and health aspects, with insufficient consideration given to urban climate recommendations. This underscores the imperative to develop robust mechanisms and resilient systems capable of coping with escalating heat stress. Addressing this challenge entails embracing a dynamic array of adaptation and mitigation strategies to address the multifaceted impacts of HWs comprehensively. HHAPs must be meticulously tailored to the specific climate, demographics, geography, infrastructure, and socio-economic dimensions of the communities they aim to safeguard. Integration of state-of-the-art knowledge is indispensable to ensure that HHAPs can effectively deliver on their intended benefits. WHO's guidance to HHAPs also outlines several principles to be adopted for planning and responding to extreme heat which underlines the need to use existing systems and response arrangements, effective communication, a multi-agency and intersectoral approach (WHO, 2008; 2021). Several principles linked with planning for and responding to extreme heat revolves around relying on established local, regional, and national emergency response systems and embracing a long-term vision. Additionally, plans require a multi-agency and intersectoral approach, ascertaining formal evaluation, effective communication to target groups and warrant that countermeasures do not worsen the issue of climate change (refer Fig. 4).

In the present study, we urge practitioners and policymakers to effectively frame a set of objectives (tasks) within each domain (meteorological, epidemiological, public health, and urban/regional planning) as a part of smart HHAPs. A detailed list of actions (short-term, medium-term and long-term) complementary to the objectives is provided in Annexure 1. This provides a clear-cut objectives and temporal actions to be taken (short-term, medium-term and long-term) by individuals/agencies directly linked with different core elements. The proposed working principle of an objective-based execution of tasks within a wider HHAP involves a circular approach which is cost effective, iterative and allows easy implementation on ground. This will provide clarity for concerned stakeholders to understand, assess, and execute intended measures. It should essentially encompass the active involvement of multiple domains (D) which typically includes experts from meteorological (D1), epidemiological (D2), public health (D3) and urban/regional planning (D4) background (see Fig. 5).

In this workflow, task managers are required to formulate explicit objectives (O) under each of their working domains (as formulated in Annexure 1). For a case, the first objective of meteorological agency can be denoted as D1O1, the second one as D2O2 and so on. The respective experts of the four domains are expected to do a similar exercise and carry out an implementation of temporal strategies. Additionally, task managers are expected to pinpoint a set of unique indicators which determines the effectiveness of intended measures as a part of the formal evaluation process. The framework entails periodic monitoring, and a diagnostic evaluation procedure which aims to provide a detailed and precise understanding of the issues at hand, which helps in creating an effective treatment or intervention plan. The cycle is completed by incorporating necessary modifications and fit for purpose updations to feed in to the (revised) guidelines of HHAPs. This results in a stronger and robust version of HHAP, which has evolved from the previous model and is now better equipped to handle new challenges.

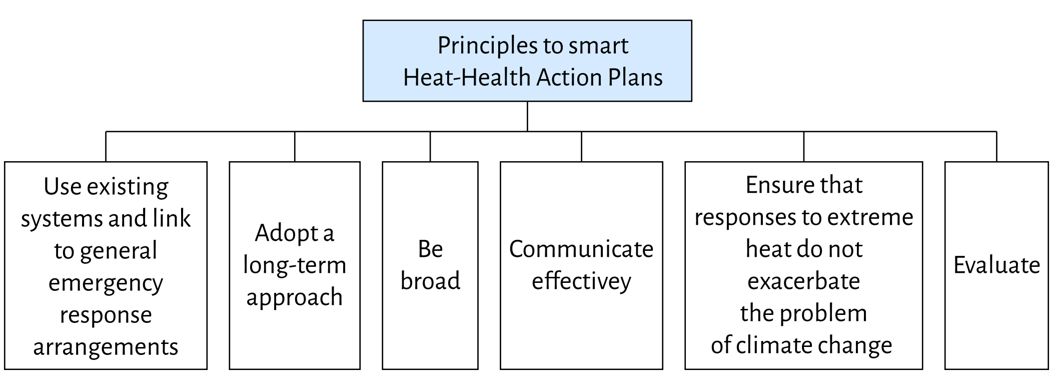

Figure 4. Key principles for effective operationalization of HHAPs

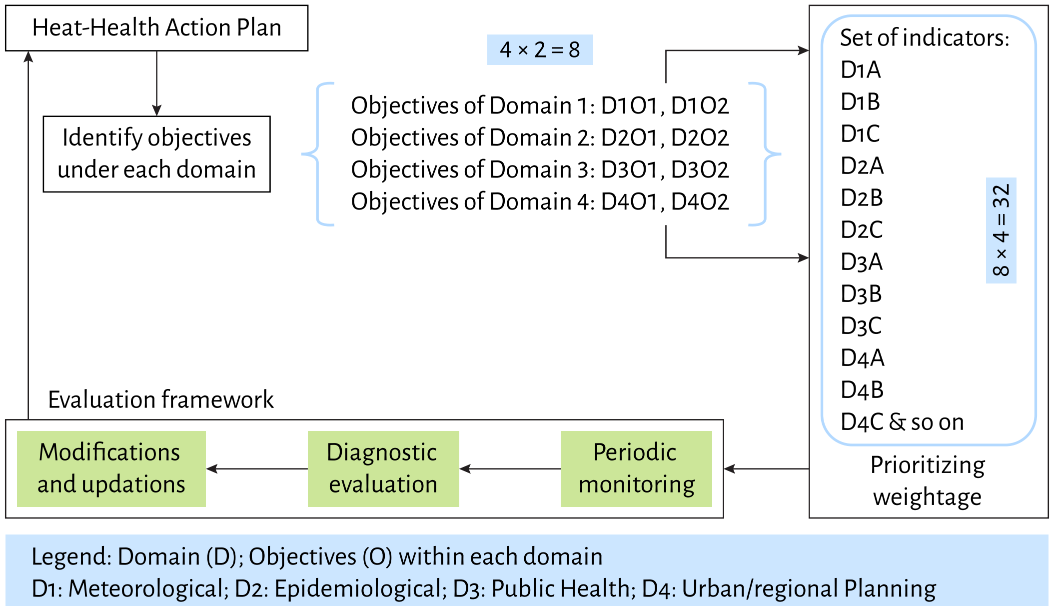

Figure 5. Representative objective-based execution of tasks within a smart HHAP

g) Support good practices of heat-health governance

Solid heat-health governance covers a broad spectrum of public-private networks and stakeholders who deliberate and make decisions regarding heat resilience (Keith et al., 2023; Wan et al., 2023; Ravishankar & Howarth, 2024). While international and national guidelines have outlined good governance principles, their translation into practice remains suboptimal. Current HHAPs often overlook rapidly changing climate and demographic variables, thereby compromising their overall effectiveness. Integrating HHAPs with other climate-sensitive early warning systems, climate-resilient adaptation plans, and disaster management policies could yield synergies and efficiency gains. Moreover, the development of heat governance extends beyond governmental purview; it is crucial to involve non-governmental stakeholders, including private and non-profit organizations, whose decisions significantly impact negating heat vulnerability. Scaling up public heat-health surveillance to inform and target adaptation plan and enhancing public health engagement present opportunities for effective health governance. Mainstreaming heat action planning across global cities, particularly in tropical regions, based on emerging best practices that prioritize closer integration of local health agencies, could enhance heat adaptation outcomes.

h) Build and improve urban heat resilience

Heat resilience, defined as the ability to construct an environment capable of withstanding and enduring extreme heat episodes, is essential (Keith & Meerow, 2022; Lim et al., 2022). Urban heat resilience necessitates an integrated planning approach that harmonizes strategies across community plans and leverages the best available heat risk information to prioritize heat mitigation efforts. Facilitative interventions can empower cities to influence and support actions toward sustainable urban cooling through appropriate policies and programs (Keith et al., 2021). HHAPs must include efforts that should be directed towards embedding urban heat resilience into city policies and plans. Additionally, escalating heat risks attributable to rapid expansion of the built environment and the UHI effect underscore the need to integrate HHAPs with development plans and urban planning policies. HHAPs can benefit from climate-based recommendations, while spatial frameworks such as local climate zone maps can offer critical insights into intra-urban variations in heat vulnerability (Kotharkar et al., 2024). Building resilience to extreme heat, necessitates concerted efforts across sectors and stakeholders to develop inclusive and effective strategies that prioritize equity and social justice.

i) Focus beyond heat management and plan for extreme heat

Historically, response mechanisms to extreme heat have been solely inclined towards managing and minimizing its negative public health outcomes (WHO, 2021; He et al., 2023). These set of countermeasures are often referred to as heat management strategies. ‘Heat management’ refers to a set of short-term actions intended to minimize the immediate negative consequences of extreme heat. The wide range of contemporary actions and traditional efforts directs a static response and focuses primarily on controlling/reducing the ill effects of extreme heat. Hence, they do not present replicability of actions across spatial scales and offer a poor signature of adaptation efforts. Conversely, smart HHAP is vocal for 'heat planning' which refers to the portfolio of provisions taken in advance with the potential to reduce the anticipated impacts of extreme heat. These primarily include long-term adaptation and mitigation strategies (design and planning), strengthening heat response systems and associated machinery to proactively translate measures into heat-related prevention efforts. It constitutes periodic monitoring and evaluation (of processes and outcomes) to evaluate practices to deal with the impacts of HWs. Simultaneously, extreme heat planning offers a practical approach to proactively direct extreme heat countermeasures and proposes a predictive method to plan and mitigate urban heat across many systems and sectors it affects.

Discussion

Over the years, heat-health research has examined various aspects of public health, urban planning, and epidemiological evidence to build a thorough and integrated understanding. Matthies & Menne (2009) examined existing HHAPs in Europe and identified best practices for national and local preparedness planning. Another enquiry by Zuo et al. (2015) explored mechanisms to address the impacts of HWs, considering their significant effects on the built environment and community health. Martinez et al. (2019) conducted an updated review of HHAPs in Europe, evaluating future challenges in heat-health governance and stakeholder engagement. In another study, Fragomeni et al. (2020) investigated a collaborative approach to integrate the knowledge of heat vulnerability and urban climatology into the development of heat response plans. Guardaro et al. (2020) focused on bridging the gap between resilience theory and practice, advocating for community-based action plans to promote heat-reducing solutions. Further investigations critically analyzed the need to strengthen connections between research and practical interventions, emphasizing the importance of two-way communication between researchers and implementers in designing effective action plans (Casanueva et al., 2019; Ebi, 2019; Kotharkar & Ghosh, 2021a).

Recent efforts have shifted focus towards practical implementation and effective interventions within urban development policies and action plans (Parsaee et al., 2019; Ulpiani et al., 2024). Efforts have been made to explore collaborative heat response planning, community action plans, and to evaluate the monitoring and effectiveness of HHAPs. The present article provides a critical perspective into contemporary extreme heat-related countermeasures and strategies within the purview of HHAPs. The primary focus of this contribution has been on understanding and responding to overheating challenges, depicting cities as the central point of the emerging issue. It deep dived into the construction of a smart HHAP which provides multidisciplinary solutions while exploring pathways to address urban overheating. The different components of a smart HHAP provides explicit recommendations for heat-health researchers and a portfolio of actions for policymakers. This includes focusing beyond heat management and converging on proactive and long-term planning, building governance structures and supporting urban resilience routes to extreme heat. Investing in multi-disciplinary, multi-scalar and multi-dimensional early warning systems can go a long way in constructing a robust and dynamic HHAP with inputs from collaborative efforts.

Conclusion

Urban overheating, driven by global climate change and rapid urban development poses a major environmental problem that adversely impacts urban systems. The present article underscored the complexity and challenges inherent in contemporary extreme heat management and planning efforts as a part of wider HHAPs. The present work describes a multidisciplinary outlook on countermeasures to urban overheating, which remains yet to be addressed in the context of anthropogenic climate change and rapid urban expansion. The barriers to addressing extreme heat risk include a lack of evidence-based guidance for planning processes, siloed research, and underdeveloped regulatory structures. Additionally, HHAPs are poorly integrated with national policies which further hamper the overall potential and effectiveness of adaptation measures. It is also important to note that HHAPs primarily adopt a public health approach and are oriented toward reducing human mortality and morbidity.

The time is now for a smart version of HHAP. It is necessary to counter the borderless nature of heat hazards and severity of heat extremes in a changing climate. A programmatic and progressive framework backed by strategic long-term investments can support HHAPs to be a game-changing apparatus. Incorporating spatial assessment of intra-urban heat risk mapping at a granular level within HHAPs is a valuable approach for addressing heat vulnerability which accounts for local climatology and urban meteorology. This helps in the knowledge of hyper-local distribution of heat, thus providing climate-based recommendations for urban planners and policy-makers to devise apposite mitigation measures. Our recommendations include the need for a dynamic stance with a mandate to apply core elements recommended by WHO, embracing a long-term approach, backed by a multidisciplinary and multi-sectoral warning system. Additionally, it promotes to develop multi-disciplinary, multi-scalar and multi-dimensional action plans aided by strong heat-health governance structures to focus proactively on early extreme heat planning. Future empirical research is crucial to examine whether institutional and policy approaches effectively enhance heat resilience in cities.

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Annexure 1. Specific actions to meet objectives for core elements in a HAP

Core element (CE)	Description	Objectives	Actions		
			Short-term (up to 3-year time span)	Medium-term (3-5 year time span)	Long-term (more than 5-year time span)
CE 1: Agreement on a lead body	to coordinate a multipurpose collaborative mechanism between bodies and institutions and to direct the response if an emergency occurs	1. To form a lead body and coordinate a multi-purpose collaboration mechanism between identified agencies/ stakeholders. 2. Set up objectives related to the management and planning of heat waves. 3. To manage the response, if an emergency occurs. 4. To set up an action plan/steering committee to drive, organize, and govern heat-related efforts.	i. Form a committee/team to oversee the progress and functioning of various preparedness measures ii. Define specific roles and responsibilities for each player iii. Establish inter-agency coordination iv. Identify a lead agency and steering committee (members of different groups) v. Formally define roles and responsibilities across spatial scales. vi. Identification of experts/ stakeholders across various domains	i. Ensure involvement of different agencies/ stakeholders in decision-making processes ii. Ensure adequate funding for sustainability and continuity of activities with support from key decision-makers iii. Conduct a cost-benefit analysis of interventions to estimate the strengths and weaknesses of decisions/intended measures.	i. Integrate HAPs with development planning processes and municipal plans. ii. Apply multi-level governance and include national, regional, and local authorities. iii. Set up protocols for emergencies. iv. Allocate part of research and development in the financial budget for heat wave action planning. v. Make provision for funding. vi. Identify potential avenues of interdisciplinary collaboration between academia and industry.
CE 2: Accurate and timely alert systems	Install heat–health warning systems to trigger warnings, determine the threshold for action, and communicate the risks	1. To provide accurate and timely warnings/forecasts of temperature and weather parameters. 2. To issue graded levels of alert/ warning as per threshold (timely communication). 3. To calculate the city-level threshold (temperature-health association) and periodic monitoring of the threshold.	i. Develop a warning system based on a local threshold or T_{max}, T_{min}, or heat indices. ii. Decide on what should be the threshold. iii. Understand and communicate warnings. iv. Track the occurrence of HWs and issue timely warnings/alerts. v. Forecast heat waves in advance. vi. Identify health conditions based on scientifically sound threshold levels. vii. Provide an effective set of response measures associated with the warning level.	i. Calculate and monitor the threshold. ii. Understand the concept of heat risk and create awareness about it. iii. Evolving communication systems, evaluating them, and communicating the warning.	i. Understanding and evolving the concept of threshold and risk. ii. Forecasting climate patterns (city/regional level model) for preparation of future hazards. iii. Establish multi-hazard warning systems and integrate them with HW action planning. iv. Include climate variability and urban warming projections in HAPs. v. Improve forecasts with advanced lead times. vi. Upgradation of forecast/early warning systems and associated equipment.

Core element (CE)	Description	Objectives	Actions		
			Short-term (up to 3-year time span)	Medium-term (3-5 year time span)	Long-term (more than 5-year time span)
CE 3: A heat-related health information plan	about what is communicated, to whom, and when & communicating the risks of hot weather and HWs and giving behavioral advice	1. To identify the mechanism, timing/issuance, language, and content of information, education, and communication (IEC) materials and activities. 2. To work out mechanisms for the involvement of non-governmental and other related organizations. 3. To establish a systematic information network for the dissemination of alerts and issue heat risk communications through public-friendly content and language.	i. Conduct public awareness and community outreach programs ii. Expand knowledge about different ways to minimize the impacts of extreme heat through precautionary measures. iii. Behavioural advice on staying indoors, avoiding strenuous work, drinking fluids, etc.	i. Prepare an operational heat response plan (including guidance and standards) linked with the warnings. ii. Build awareness, perception, and adaptive capacity to extreme heat. iii. Identify the mechanism of issuing a clear plan of communication for different sectors.	i. Collaborate with non-government organizations and engage civil society groups. ii. Engage and collate research on the detrimental impact of hot weather episodes on public health. iii. Explore the possibility of a dynamic system to show real-time data portals using information and communication technology (ICT).
CE 4: A reduction in indoor heat exposure (in vulnerable areas and public buildings)	epidemiological information to reduce indoor heat, indoor cooling strategies	1. To improve knowledge of indoor overheating and its impact on health. 2. To provide behavioral advice on ways to cool indoor spaces. 3. To bring awareness about continuous exposure to indoor heat risk and strategies to reduce nocturnal discomfort in indoor spaces. 4. To promote green building concept.	i. Identify vulnerable areas and public buildings (typology) for intervention. ii. Conduct diagnostic studies to identify issues in buildings and direct possible countermeasures. iii. Improve wall/roof insulation and ventilation in existing building structures. iv. Reduce internal heat load. v. Reduce heat stress and increase ventilation for indoor spaces. vi. Increase albedo using light-colored materials for cool roofs/ pavements, etc. vii. Allow necessary retrofitting in building envelopes. viii. Incorporate standards to provide thermal comfort in buildings	i. Reduce indoor heat exposure and achieve sustainable thermal comfort in buildings. ii. Allow modifications in housing and introduce appropriate urban landscape measures. iii. Introduce passive cooling and efficient active cooling technologies. iv. Employ measures to reduce local heat islands.	i. Conduct research efforts on understanding the relationship between indoor temperatures and indoor thermal comfort. ii. Adopt a nuanced approach toward air-conditioning to check greenhouse gas emissions. iii. Evaluate the effectiveness of cooling strategies e.g., cool/ green roof, wall insulation, and their potential to reduce heat vulnerability.

Core element (CE)	Description	Objectives	Actions		
			Short-term (up to 3-year time span)	Medium-term (3-5 year time span)	Long-term (more than 5-year time span)
CE 5: Particular care for vulnerable population groups	identification and localization of the most vulnerable population groups, active surveillance programme & preparatory measures to strengthen active outreach activities	1. To identify and make arrangements for vulnerable population groups. 2. To identify heat-prone areas and direct extreme heat countermeasures spatially. 3. To identify determinants of heat vulnerability/risk.	i. Prepare targeted plans to reduce immediate heat-health risks. ii. Mobilize human resources to provide relief material. iii. Establish cooling centers and shaded spaces in public areas and arrange distribution of water, medicines, etc. iv. Setting up temporary outreach clinics in remote areas. v. Ensure occupational safety, rest hours, and shelters for the outdoor working population.	i. Improve housing conditions. ii. Hotspot mapping for vulnerable areas and communities. iii. Conduct heat vulnerability/risk studies. iv. Involve participation of local NGOs or volunteer-based organizations for outreach to vulnerable groups.	i. Undertake heat risk perception and epidemiological studies to understand the impact of extreme heat on various population groups.
CE 6: Preparedness of the health and social care system	an operational plan on the specific procedures hospitals, clinics, retirement, and nursing homes should adopt before and during the summer period and during HWs needs to be defined; these actions need to be linked to heat-health warnings issued	1. To conduct appropriate staff training and planning, and guidance to health professionals on heat illness risk factors, diagnosis, and management. 2. To improve basic health infrastructure. 3. To allow building modifications and interventions to reduce indoor overheating in health care facilities. 4. To build climate-resilient health systems. 5. To improve emergency planning, preparedness, management, planning, and response in health care settings through national/ international initiatives.	i. Establish Standard Operating Procedures (SOPs), preparedness and anticipatory measures. ii. Train healthcare professionals and staff on specific clinical care and health. iii. Establish treatment protocol for high-risk patients. iv. Establish emergency planning and procedures. v. Enhance the preparedness of healthcare providers and facilities. vi. Maintain adequate stock of life-saving drugs and medicines vii. Establish a heat hotline emergency number. viii. Conduct mass awareness campaigns on improving heat-health outcomes.	i. Conduct studies to understand the relation between various vector-borne diseases and extreme events. ii. Develop surge strategies to manage increased demand iii. Develop contingency plans for staff. iv. Develop and modify curricula for training health professionals.	i. Augment health infrastructure and undertake building modifications and interventions to reduce indoor overheating ii. Allow modifications for reduction of carbon footprint in health care facilities.

Core element (CE)	Description	Objectives	Actions		
			Short-term (up to 3-year time span)	Medium-term (3-5 year time span)	Long-term (more than 5-year time span)
CE 7: Long-term urban planning	adaptation measures in built environment to focus on heat resilient cities, reducing urban heat islands and outdoor heat stress with energy efficiency measures	1. To promote actions to design climate-resilient cities. 2. To evaluate the changing dynamics of built environment. 3. To develop and implement climate-sensitive urban planning policies/guidelines.	i. Install canopies and roof structures to provide external shading. ii. Encourage water harvesting. iii. Introduce green roofs and vertical gardens.	i. Urban greening and improve overall green cover in cities. ii. Urban landscape management and other interventions in the built environment to reduce heat islands. iii. Promote walkability and cycle-friendly cities. iv. Enhance & protect existing urban forestry. v. Plan and implement activities to make cool communities. vi. Make provisions for water planning and management in cities. vii. Invest and explore available cooling technologies for existing buildings. viii. Conduct programmes that include housing, environmental, infrastructure improvements, and resource conservation. ix. Implement green building rating systems across spatial scales.	i. Introduce appropriate provisions in development control regulations. ii. Integrate HAPs with development plans and urban/regional planning, energy, transport, and climate change adaptation policies. iii. Support blue-green infrastructure interventions and water-sensitive urban design. iv. Modulate floor space index (FSI) and urban morphological parameters and heat resilient infrastructure development. v. Invest in sustainable and non-motorized transport options to minimize GHG emissions. vi. Generate heat wave vulnerability/risk map for developing strategic adaptation/ mitigation solutions. vii. Conduct diagnostic studies on built environment including UHI/ heat stress/heat risk/pollution.
CE 8: Real-time surveillance and evaluation	communication and collaboration between several institutions, groups, and actors; periodically monitoring the health impacts of HWs and the effectiveness of the interventions; regular evaluation of heat-health action plans	1. To conduct periodic evaluation and monitoring of measures in HAPs 2. To define elements that need improvement (cost-effectiveness of interventions, reducing practical barriers) 3. Set up real-time surveillance systems so that prevention and response measures can be adjusted	i. Establish communication and collaboration between related institutions/groups to monitor changing climatic conditions ii. Conduct process evaluation of measures applied to reduce the impacts of extreme heat. iii. Conduct cyclic evaluation of various measures applied to reduce heat vulnerability/risk.	i. Evaluate whether the measures introduced are ethical and reduce inequalities. ii. Monitor health impacts and changes over time	i. Periodically monitor, review, and evaluate the performance of action plans ii. Evaluate the effectiveness of warning systems and allow modifications iii. Conduct outcome evaluation of intended measures to assess whether policies are valid in reducing heat-health outcomes.